

**TITLE**

# METHOD AND APPARATUS FOR DETERMINING DISK DRIVE PARAMETER IN ACCORDANCE WITH AMBIENT TEMPERATURE

## CLAIM OF PRIORITY

This application makes reference to, incorporates the same herein, and claims all benefits accruing under 35 U.S.C. §119 from my application entitled *METHOD AND APPARATUS FOR DETERMINING PARAMETERS OF DISK DRIVE IN USER'S CONDITION* filed with the Korean Industrial Property Office on 19 February 2001 and there duly assigned Serial No. 8138-2001.

## BACKGROUND OF THE INVENTION

## Field of the Invention

The present invention relates to a disk drive and a method of controlling the same and, more particularly, to a method and apparatus for determining disk drive parameters in accordance with ambient temperature.

## Description of the Related Art

Generally, the features of a magneto-resistive write and read head for respectively recording and reproducing information on a disk of a hard disk drive can be optimized by varying a variety of parameters affecting the performance of the hard disk drive during a burn-in process customarily performed during manufacture of the hard disk drive. That is, values of various parameters

1 corresponding to a channel factor, which optimizes the features of read and write channels, are  
2 controlled during the burn-in process.

3 In a hard disk drive, changes in a head media signal as well as mechanical changes occur due  
4 to fluctuations of environmental conditions such as temperature that deleteriously affect the  
5 performance of the hard disk drive. For these reasons, I have found that there is a need to correct  
6 parameters of the hard disk drive in accordance with changes of temperature. In this regard,  
7 Japanese Laid-Open Patent Publication No. Hei 10-340412 discloses an information memory device  
8 capable of sensing variations in temperature and attempting to correct the write current to a  
9 predetermined value found in a look-up table.

10 I have found that changes in temperature below the ambient temperature result in changes  
11 in the flying height of a head, the magnetic coercive force of a disk, a rate of variation of the  
12 resistance of the magneto-resistive (MR) head and non-linear transmission shift (NLTS) of the head.  
13 In contemporary practice however, only one parameter of a hard disk drive, namely the write current,  
14 is corrected in accordance with variations in the temperature surrounding a hard disk drive; other  
15 parameters related to thermal change are maintained at fixed values. Therefore, it is difficult to  
16 obtain the optimum performance of the hard disk drive and thus the quality of the performance of  
17 the hard disk drive deteriorates.

## 18 SUMMARY OF THE INVENTION

19 It is therefore, an object of the present invention to provide an improved disk drive and  
20 process for controlling a hard disk drive.

1        It is another object to provide a hard disk drive and a process that compensate for variations  
2        in temperature of the hard disk drive.

3        It is still another object to provide a hard disk drive and a process that compensates for the  
4        affects of variations in temperature upon multiple parameters that influence the operation of the hard  
5        disk drive.

6        It is yet another object to provide a memory such as a hard disk drive and operational process  
7        that endeavors to continuously maintain those operational characteristics of the memory that may  
8        change as a result of ambient variations, at values that stabilize the performance of the memory to  
9        conform to its operational characteristics exhibited while the memory is exposed to ambient  
10      conditions within a critical range.

11      It is still yet another object to provide a method and apparatus for determining disk drive  
12      parameters in accordance with ambient temperature, and after determining the ambient temperature,  
13      to adjust those parameter values that are determined during a burn-in process and that are also  
14      affected by temperature to be compatible with the determined ambient temperature in consideration  
15      of changes in the performance of the hard disk drive attributable to temperature, thus allowing the  
16      hard disk drive to operate with optimum performance.

17      These and other objects may be achieved with a hard disk drive and a process for determining  
18      parameters of a hard disk drive that may be influenced by ambient temperature, by the expedient of  
19      updating temperature information by measuring the temperature in the disk drive during a  
20      predetermined mode. A determination is then made about whether the updated temperature  
21      information falls within a critical temperature range. Write and read parameters are designated as

1 parameters that are affected by temperature in order to compensate for variations in the performance  
2 of the hard disk drive due to any excess temperature after considering the relationship of the write  
3 and read parameters and the thermal change, when the thermal information indicates that the updated  
4 temperature exceeds the critical temperature range.

5 These objects may also be achieved with a process and apparatus that determines parameters  
6 of a hard disk drive influenced by ambient temperature, that may be constructed with a memory  
7 storing information regarding a variety of parameters and the measured temperature of the disk drive.  
8 A temperature sensor senses the temperature in the disk drive, and a controller that updates  
9 temperature information detected by the temperature sensor in the memory during a predetermined  
10 operational mode, compares the updated temperature information and a critical temperature range,  
11 and changes write and read parameters that are affected by temperature, from among those  
12 parameters stored in the memory in order to compensate for variations in the performance of the disk  
13 drive in correspondence with the excess temperature, and in consideration of the relation between  
14 the read and write parameters and the thermal change, whenever the updated temperature rises  
15 above, or drops below, the critical temperature range.

16 **BRIEF DESCRIPTION OF THE DRAWINGS**

17 A more complete appreciation of the invention, and many of the attendant advantages thereof,  
18 will be readily apparent as the same becomes better understood by reference to the following detailed  
19 description when considered in conjunction with the accompanying drawings, in which like reference  
20 numerals indicate the same or similar components, and wherein:

1 FIG. 1 is a plan view of a structure of a hard disk drive constructed according to the  
2 principles of the present invention;

3 FIG. 2 is a schematic diagram illustrating an apparatus able to determine parameters of the  
4 disk drive in accordance with ambient temperature according to the principles of the present  
5 invention;

6 FIG. 3 is a flowchart illustrating one process for determining parameters of the disk drive in  
7 accordance with ambient constructed as a first embodiment of the principles of the present invention;  
8 and

9 FIG. 4 is a flowchart illustrating another process for determining parameters of the disk drive  
10 in accordance with ambient temperature constructed as a second embodiment of the present  
11 invention.

## 12 DETAILED DESCRIPTION OF THE INVENTION

13 Turning now to the drawings, FIG. 1 shows a structure of a hard disk drive 10 constructed  
14 according to the principles of the present invention. Hard disk drive 10 includes at least one and  
15 possibly a plurality of magnetic disks 12 that may be rotated by a spindle motor 14 and a transducer  
16 which is positioned near corresponding a planar surface 18 of disk 12.

17 Data and other information may be stored in the form of binary bits on surface 18 while  
18 spindle motor 14 rotates disk 18 around its axis. Transducer 16 reads or writes information on the  
19 rotating disk 12 by sensing and magnetizing a magnetic field borne by surface 18 of the disk 12.  
20 Here, although the transducer 16 is empirically described as a single body, it must be understood that

1 a transducer may be constructed with two separate bodies, namely a write transducer for magnetizing  
2 the disk 12 and a read transducer for sensing the magnetic field borne by disk 12. The read  
3 transducer may be composed of a magneto-resistive (MR) device. Also, the transducer 16 may be  
4 configured to be included in a slider 20 mounted on the distal end of head gimbal assembly 22.

5 Slider 20 has a structure in which an air bearing is formed in the intermediate space between  
6 the transducer 16 and the disk surface 18 and is coupled with a head gimbal assembly 22. The head  
7 gimbal assembly 22 is attached to an actuator arm 24 that bears a voice coil 26 at its radially opposite  
8 end. Voice coil 26 is positioned near a magnet assembly 28 that is coupled with a voice coil motor  
9 (VCM) 30. An electrical current provided to the voice coil 26 generates a torque which rotates the  
10 actuator arm 24 about a bearing assembly 32, and the rotation of the actuator arm 24 causes the  
11 transducer 16 to move somewhat radially across disk surface 18.

12 Information is originally stored in a plurality of annular tracks 34 on surface 18 of the disk  
13 12. Each of tracks 34 generally includes a plurality of sectors. Transducer 16 is moved by motor  
14 30 across surface 18 to read information from or record information in the tracks.

15 FIG. 2 shows an apparatus for determining disk drive parameters in accordance with ambient  
16 temperature. The apparatus includes a disk 12, a read and write head 202 being transducer 16, a  
17 preamp 203, a read channel 204, a write channel 205, a controller 206, a temperature sensor 207 and  
18 a memory 208 that are operatively interconnected as described below.

19 In the general operation of a hard disk drive, when data is read from the hard disk drive, a  
20 signal read by head 202 from disk 12 is amplified by preamp 203 so that the signal can be more  
21 faithfully signal-processed. Then the amplified analog signal is converted into a digital signal to be

1 readable by a host computer (not shown) and the digital signal is transmitted to the host computer  
2 via a host interface. When data is written on disk 12 however, user data is received from the host  
3 computer via the host interface and is converted into an electric analog signal in write channel 205  
4 and then a write current amplified by preamp 203 is recorded on disk 12 via MR head 202.

5 According to the method of determining disk drive parameters influenced by ambient  
6 temperature according to the present invention, the performance of a hard disk drive is in  
7 correspondence with the change of the ambient temperature of the hard disk drive. For instance, if  
8 ambient temperature changes from normal temperature to low temperature, the characteristic  
9 performance of several structural and operational features of the hard disk drive change, namely: (i)  
10 the epoxy used for binding a slider and a suspension contract, and as a result, the crown in the slider  
11 is increased, thus raising the flying height of the head; (ii) the magnetic coercive force ( $H_c$ ) of disk  
12 is increased to about  $15 H_c/1^\circ C$ ; (iii) variations in the resistance of an MR head 202 ( $\Delta R/R$ ) are  
13 reduced; and (iv) the non-linear transmission shift (NLTS) of head 202 is changed.  $H_c$  is a coercive  
14 force of the recording medium which increases as the ambient temperature decreases. When  $H_c$   
15 becomes too great, it is difficult to write data onto the recording medium. Note that in the ratio  
16  $\Delta R/R$ , "R" is a resistance value of the MR head when an external magnetic field is not applied to  
17 the MR head. " $\Delta R$ " corresponds to an amount of increase in the resistance of the MR head when  
18 a predetermined external magnetic field is applied in a reproduction mode. Since the value of  $\Delta R$   
19 varies according to the ambient temperature, its variation affects the reproduction process.

20 To correct such problems, according to the present invention, parameters are changed by  
21 using the following techniques. First, the length of a write booster is altered to compensate for

1 variations in the flying height of head 202, the magnetic coercive force  $H_c$  and non-linear  
2 transmission shift (NLTS) of head 202. That is, if the ambient temperature of a hard disk drive is  
3 decreased too much, the rise time of the write current may be reduced by altering the magnitude of  
4 the write booster. Second, a value for controlling a write precomp may be altered in order to  
5 compensate for variations in the flying height and non-linear transmission shift (NLTS) of head 202.  
6 Third, a read bias current value may be increased in order to compensate for variations in the  
7 resistance ( $\Delta R/R$ ) of the MR head 202. Fourth, the amplitude of the write current value may be  
8 increased to compensate for variations in the flying height and magnetic coercive force of head 202.

9  
10 In summary, to compensate for variations in the performance of the hard disk drive in  
11 response to thermal variation, parameters related to the read bias current factor and parameters for  
12 writing that include a write current determination factor, the write booster determination factor and  
13 the write precomp factor, are determined either empirically or based on experiments or statistics, so  
14 that the performance of the hard disk drive can be optimized in compensation for changes in the  
15 performance of the drive that are attributable to the thermal variation.

16 To achieve this result, memory 208 contains information regarding parameters for writing,  
17 which includes the write current determination factor, the write booster determination factor and the  
18 write precomp factor with respect to temperature change, and parameters for a read bias current  
19 factor, as well as information regarding parameters related to the operation of the hard disk drive,  
20 measured temperature and temperature used during the burn-in process. The parameters stored with  
21 their initial values in memory 208 are the optimum parameters that are determined during the burn-in  
process, which is one of the processes performed during the manufacture of hard disk drive 10.

1       Temperature sensor 207, a device for sensing the temperature in the hard disk drive, includes  
2       a temperature sensitive element, and generates temperature information corresponding to the sensed  
3       temperature value. “ $T_{min}$ ” corresponds to a minimum critical temperature at which the parameter  
4       values set in the burn-in process need to be changed. “ $T_{max}$ ” corresponds to a maximum critical  
5       temperature at which the parameter values set in the burn-in process need to be adjusted. “ $T$ ”  
6       corresponds to the ambient temperature detected by sensor 207 under user conditions. “ $T_0$ ”  
7       corresponds to a temperature of a place where the burn-in process is performed during the  
8       manufacture of disk 10. “ $T_f$ ” corresponds to a temperature obtained by subtracting  $T_0$ , the  
9       temperature in the burn-in process, from  $T$ , an ambient temperature occurring under user conditions.  
10       $T_{min}$ ,  $T_{max}$ , and  $T_0$  are obtained through experimentation.

11      Controller 206 updates memory 208 with the temperature information received from  
12      temperature sensor 207 while the disk drive 10 is in an idle mode during the power-on state, at  
13      regular intervals having a predetermined period, and compares the updated temperature information  
14      already stored in memory 208 with the critical temperature range established during the burn-in  
15      process. Thereafter, in the event that the updated temperature information exceeds the critical  
16      temperature range, controller 206 executes a routine process to change the values of those parameters  
17      for writing including the write current determination factor, the write booster determination factor  
18      and the write precomp factor, which are affected by thermal variation, to values that are compatible  
19      with the excess temperature.

20      Referring to the flowcharts shown in FIGS. 3 and 4, the operation of the apparatus shown in  
21      FIGS. 1 and 2 will be described together with the details of those processes according to the

1 principles of the present invention.

2 In one technique for adjusting disk drive parameters in accordance with ambient temperature  
3 in the first embodiment of the present invention, as shown in FIG. 3 controller 206 determines  
4 whether the hard disk drive is in power-on mode (step 301). When the hard disk drive is in power-  
5 on mode, controller 206 determines if the present mode corresponds to the idle mode (step 302). The  
6 idle mode is an idle state of operation in which execution of an input command has been terminated  
and reception of a new user command is awaited by hard disk drive 10. If the hard disk drive is in  
7 the idle mode, temperature sensor 207 perceives the temperature in the hard disk drive and generates  
8 temperature information corresponding to that perceived temperature (step 303). The temperature  
9 sensor 207 may be either arranged to be constructed either independently of other constitutional  
10 elements or be included within the monolithic structure of the module for preamp 203.

11 Next, controller 206 updates the temperature information  $T$  stored in memory 208 with the  
12 temperature information generated by temperature sensor 207 at regular intervals exhibiting a  
13 predetermined period, e.g. a period of ten minutes, during the idle mode (step 304). Then, controller  
14 206 compares the updated temperature information  $T$  and the lower limit of temperature information  
15  $T_{min}$  for the critical temperature range, which is established during the burn-in process (step 305).  
16 When the updated temperature information  $T$  is determined during step 306 to have a lower value  
17 than the lower limit temperature information  $T_{min}$ , controller 206 updates parameters related to the  
18 read bias current factor and parameters for writing including the write current determination factor,  
19 the write booster determination factor and the write precomp factor among other parameters that are  
20 stored in the memory 208 and that are substantially affected by temperature change, to values that  
21

1 compensate for the lower updated temperature information. At this time, values of these parameters  
2 may be adjusted by controller 206 in order to adjust the performance and operation of disk drive 10  
3 by, for example, adding corrected values that are statistically calculated through experiments at the  
4 corresponding lower temperature and stored in memory 208.

5 On the other hand, when the updated temperature information  $T$  is either equal to or greater  
6 than the lower limit of temperature information  $T_{\min}$ , controller 206 goes to step 307 and compares  
7 the updated temperature information  $T$  and the upper limit of temperature information  $T_{\max}$  of the  
8 critical temperature range established during the burn-in process, and updates the values of  
9 parameters stored in memory 208 that are related to the read bias current factor and parameters for  
10 writing, including the write current determination factor, the write booster determination factor and  
11 the write precomp factor among other parameters stored in memory 208 that are substantially  
12 affected by temperature change, to compensate for the higher temperature when the updated  
13 temperature information  $T$  has a value that is determined in step 308 to be larger than that of the  
14 upper limit of temperature information  $T_{\max}$ .

15 The parameter values stored in memory 208 need not be updated in the event that the updated  
16 temperature information  $T$  falls within the critical temperature range, that is, the updated temperature  
17 information  $T$  is greater than or equal to the lower limit of the temperature information  $T_{\min}$  and is  
18 less than or equal to the upper limit of the temperature information  $T_{\max}$ .

19 In the method of another technique for adjusting disk drive parameters in accordance with  
20 ambient temperature according to another embodiment of the present invention, as shown in FIG.  
21 4 controller 206 determines during step 401 whether hard disk drive 10 is in a power-on mode.

1 When the hard disk drive is in a power-on mode, controller 206 determines during step 402 whether  
2 the present mode of operation of hard disk drive 10 corresponds to the idle mode. If the hard disk  
3 drive is in its idle mode, temperature sensor 207 senses the ambient temperature in the hard disk  
4 drive and in step 403 generates temperature information corresponding to that sensed temperature.  
5 Then, in step 404 controller 206 updates the temperature information stored in memory 208 with the  
6 temperature information generated by temperature sensor 207 at regular intervals having a  
7 predetermined period during the idle mode. Next, in step 405 controller 206 obtains a temperature  
8 difference  $T_f$  by subtracting the temperature information  $T_0$  established during the burn-in process,  
9 which is read from memory 208, from the updated temperature information  $T$  corresponding to  
10 ambient temperature in hard disk 10. After making a comparison during step 406 of the absolute  
11 value of the temperature difference  $T_f$  and a tolerance  $C_0$ , the parameter values stored in memory  
12 208 are not updated when the absolute value of the subtracted temperature information  $T_f$  is less than  
13 or equal to the tolerance  $C_0$ , because this indicates that the present temperature condition is similar  
14 to the temperature condition established during the burn-in process.

15 The "tolerance  $C_0$ " refers to the maximum amount the temperature can vary from  $T_0$  in a  
16 burn-in process without having to change the set values of parameters in order to maintain normal  
17 performance. That is, the parameter values need not be changed at temperatures within a range of  
18  $(T_0 - C_0)$  to  $(T_0 + C_0)$  in the burn-in process. When the sensed ambient temperature is outside the above  
19 temperature range, the parameter values must be adjusted in order to compensate for the temperature  
20 variation. The value of  $C_0$  is obtained through experimentation.

1        When the absolute value of the subtracted temperature information  $T_f$  is larger than the  
2        tolerance  $C_0$  however, the parameter values must be adjusted in order to conform to the thermal  
3        variation. At this time, the parameters stored in memory 208 that are related to the read bias current  
4        factor and the parameters for writing, which include the write current determination factor, the write  
5        booster determination factor and the write precomp factor among parameters, which are substantially  
6        affected by thermal variation, are changed in step 407 to adapt to the current ambient temperature  
7        based on the value of the temperature difference  $T_f$  obtained in step 405. The optimum parameter  
8        values to compensate for variations in the ambient user temperature can be calculated by substituting  
9        the temperature difference  $T_f$  for a parameter-operational expression which is obtained statistically  
10        through simulation. In step 408, the parameter values stored in memory 208 are changed to  
11        correspond to those obtained in step 407.

12        In the above-described exemplars of embodiments of the principles of the present invention,  
13        parameters that are markedly affected by temperature are enumerated as parameters for writing  
14        including the write current determination factor, the write booster determination factor and the write  
15        precomp factor, and the parameters related to the read bias current factor. Other, read/write  
16        parameters such a filter tap determination factor, a filter booster determination factor and a filter  
17        blocking frequency determination factor, or a servo parameter can be added to the above-described  
18        parameters.

19        Through these techniques, a variety of parameters that affect the operation and performance  
20        of a hard disk drive can be reset to conform to ambient temperature by using the relationship  
21        therebetween in accordance with the thermal variation, thus allowing a hard disk drive to operate

1 with optimum performance despite thermal variations in ambient temperature.

2 The principles of the present invention may be incorporated into a method, apparatus or  
3 system. It may be appreciated therefore, that the practice of the present invention endeavors to  
4 continuously maintain those environmentally sensitive operational and structural characteristics of  
5 a memory such as, by way of example, a hard disk drive, at values that stabilize the performance of  
6 the memory to conform to its operational and structural characteristics exhibited while the memory  
7 is within a critical range of ambient conditions. If implemented with software, elements constituting  
8 the present invention are represented by code segments that execute the necessary operations. The  
9 program or code segments may be stored in a processor-readable medium or may be transmitted by  
10 a computer data signal that is modulated onto a carrier wave in a transmitting medium or  
11 communications network. Any medium that stores or transmits information such as an electric  
12 circuit, a semiconductor memory device, a ROM, a flash memory, an erasable ROM, a floppy disk,  
13 an optical disk, a hard disk, an optical fiber medium and a radio frequency (RF) network may be used  
14 as the processor-readable medium. The computer data signal is a signal that can be transmitted on  
15 an electric network channel, optical fiber, air, electric system, radio frequency network and on other  
16 media of signal transmission.

17 In specific embodiments of the present invention, the individual values of the several write  
18 and read parameters may be adjusted individually and independently from one another when the  
19 controller determines that an ambient environmental condition such as the temperature of the  
20 memory apparatus, is outside of the critical range, either by changing the values of these parameters  
21 with preset incremental values, by reference to look-up tables indexed by the amount that the

1 ambient temperature exceeds the nearest value of the critical range, or by operation of an equation  
2 upon that amount. Alternately, in a different embodiment, several or all of the values of the several  
3 write and read parameters may be adjusted together and *en masse*, so that the adjustment of one value  
4 may reflect the adjustment in value of one or more of the other values of the parameters, so as to  
5 simultaneously compensate for both changes in the functional and structural characteristics of the  
6 memory device as well as for changes in the values of the other write and read parameters, in order  
7 that the operational performance of the memory will faithfully mimic its performance while  
8 operating within the critical range. In the foregoing embodiments, temperature was used as an  
9 exemplary environment condition that affects the structural and functional characteristics, and thus  
10 the operational performance of the memory device.

11 The foregoing paragraphs describe a method and apparatus that determines disk drive  
12 parameters in accordance with ambient temperature, with the values of various parameters affected  
13 by temperature being controlled and automatically changed to values corresponding to the changed  
14 ambient temperature when an environment where the hard disk drive is installed changes, thereby  
15 allowing the hard disk drive to operate with optimal performance. While the present invention has  
16 been particularly shown and described with reference to the several embodiments thereof, the present  
17 invention is not restricted to those embodiments. Further, it will be understood by those skilled in  
18 the art that various changes in form and details may be made without departing from the spirit and  
19 scope of the invention as defined by the appended claims.

20 As described above, according to the present invention, parameter values, which are sensitive  
21 to the temperature of a hard disk drive, may be modified or controlled using the relationship between

1 the values of those parameters and the temperature of the hard disk drive in accordance with the  
2 present ambient temperature, thereby preventing any deterioration in the performance of the hard  
3 disk drive even when the temperature at the burn-in process and present ambient temperature are  
4 different.